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FLOW SYSTEM FOR PRESSURE CASTING

This invention relates to an improved alloy flow system for use in the pressure casting of alloys.

In a number of recent patent applications, we have disclosed inventions relating to the pressure casting of alloys, utilising what is referred to as a controlled expansion port (or CEP). Those applications include PCT/AU98/00987, relating to magnesium alloy pressure casting and PCT/01/01058, relating to aluminium alloy pressure casting. They also include the further applications PCT/AU01/00595 and PCT/AU01/01290, as well as Australian provisional applications PR7214, PR7215, PR7216, PR7217 and PR7218 each filed on 23 August 2001. These further applications relate variously to the pressure casting of magnesium, aluminium and other pressure castable alloys and to devices and apparatus for use in pressure casting of those alloys.

As indicated, a CEP is utilised in the inventions of the above-identified patent applications. A CEP is a relatively short part of the alloy flow path which increases in cross-sectional area, from an inlet end to an outlet end of the CEP, such that alloy flowing through the CEP has a substantially lower flow velocity at its outlet end relative to the inlet end. The reduction in flow velocity is such that, in its flow through the CEP, the alloy undergoes a change in its state. That is, with molten alloy received from a pressurised source of supply to the inlet end of the CEP, the reduction in flow velocity from that attained at the inlet end to that at the outlet end is such that the state of the alloy changes from the molten state at the inlet end to a semi-solid or thixotropic state at the outlet end.

In its flow beyond the outlet end, and substantially throughout a die cavity with which the flow path communicates, the alloy most preferably is retained in the semi-solid or thixotropic state. With sufficiently rapid solidification of alloy in the die cavity, and back from the die cavity back to or into the CEP, a resultant casting produced is able to be characterised by a microstructure having fine, spheroidal or rounded primary particles of degenerate dendritic form in a matrix of secondary phase.

In our co-pending application PCT/AU03/00195, there is disclosed a metal flow system for high pressure die casting, and a method of producing alloy castings using a high pressure die casting machine. The system and

method of that application utilises a flow path including a CEP, but also including a CEP exit module, referred to as a CEM, through which alloy from the outlet of the CEP passes in its flow to a die cavity. In the CEP, the alloy undergoes a change of state, from a molten state to a semi-solid state, as a consequence of being subjected to a sufficient reduction of flow velocity in the CEP from a suitable flow velocity at the inlet end of the CEP. The CEM has a form which controls the alloy flow whereby the alloy flow velocity decreases progressively from the level at the outlet end of the CEP, such that, at the location at which the flow path communicates with the die cavity, the alloy flow velocity is at a level significantly below the level at the outlet end of the CEP, the change in state generated in the CEP is maintained substantially throughout filling of the die cavity, and the alloy is able to undergo rapid solidification in the die cavity and back along the flow path towards the CEP.

We have found that the form of a CEM can be utilised to advantage in other applications. This use of the form of a CEM is highly surprising in that it is contrary to conventional practice, systems and apparatus for high pressure die casting.

As indicated above, "CEM" represents an exit module for a CEP. That terminology is not appropriate for the present invention in that a CEP is not used. Rather, the invention utilises a flow path which has an exit module through which alloy flows from a runner to a die cavity. While the exit module of the invention has a form suitable for a CEM, it is distinguished herein as a flow-path exit module or "FEM".

The invention provides a metal flow device for high pressure die casting of alloys using a machine having, or operable to provide, a pressurised source of molten alloy and a mould defining at least one die cavity, wherein the device defines a metal flow path by which alloy received from the pressurised source is able to flow into the die cavity, wherein:

(a) a first part of the length of the flow path includes a runner; and

(b) a second part of the length of the flow path from an outlet end of the runner includes a flow-path exit module (FEM); and

wherein the FEM has a form which controls the alloy flow whereby the alloy flow velocity decreases progressively from the level at the outlet end of the runner whereby, at a location at which the flow path communicates with the die cavity,

the alloy flow velocity is at a level significantly below the level at the outlet end of the runner and such that, on filling of the die cavity, the alloy is able to undergo solidification in the die cavity and back along the flow path towards the runner.

Additionally, the invention provides a pressure casting machine for high pressure die casting of alloys, wherein the machine has, or operable to provide, a pressurised source of molten alloy, a mould defining at least one die cavity, and a metal flow device which defines a metal flow path by which alloy received from the pressurised source is able to flow into the die cavity, wherein:

(a) a first part of the length of the flow path includes or comprises a runner; and

(b) a second part of the length of the flow path from an outlet end of the runner includes a flow-path exit module (FEM); and

wherein the FEM has a form which controls the alloy flow whereby the alloy flow velocity decreases progressively from the level at the outlet end of the runner whereby, at a location at which the flow path communicates with the die cavity, the alloy flow velocity is at a level significantly below the level at the outlet end of the runner and such that, on filling of the die cavity, the alloy is able to undergo solidification in the die cavity and back along the flow path towards the runner.

The invention also provides a method of producing alloy castings using a high pressure die casting machine having, or operable to provide, a pressurised source of molten alloy and a mould defining at least one die cavity, in which the alloy flows from the source to the die cavity along a flow path, wherein:

(a) the alloy, in a first part of the flow path, is caused to flow along a runner; and

(b) in a second part of the flow path, between the first part and the die cavity, the alloy flow is controlled whereby the flow velocity progressively decreases from the level at an outlet end of the runner to a flow velocity where the flow path communicates with the die cavity which is at a level significantly below the level at the outlet of the runner.

As indicated, the second part of the flow path decreases the alloy flow velocity below the flow velocity level at the outlet end of the runner. The second

part of the flow path is herein more briefly referred to as the "flow-path exit module" or "FEM".

Preferably the runner has a cross-sectional area at least at its outlet end such that, at an alloy mass flow rate able to be generated by the machine, the runner will result in an alloy flow velocity at the outlet end of the runner in excess of about 60 m/s up to about 180 m/s for a magnesium alloy and in excess of about 40 m/s up to about 120 m/s for alloys other than magnesium alloys. In one arrangement, the FEM increases in transverse cross-sectional area in a direction extending beyond the outlet end of the runner, whereby the decrease in alloy flow velocity is able to preclude a change of state of the alloy from a molten state to a semi-solid state exhibiting thixotropic properties. In another arrangement the increase in cross-sectional area is such that the decrease in the flow velocity is able to prevent the alloy from undergoing a change of state to enable die cavity fill by molten alloy. A gate defined at the outlet end of the flow path may provide a constriction to alloy flow therethrough, although it need not provide such a constriction. In one form, the gate is at the outlet end of the FEM. In another form, the outlet end of the FEM is spaced from the gate by a secondary runner which has a cross-sectional area at least equal to the cross-sectional area at the outlet end of the FEM.

With the present invention, the die cavity fill is able to be achieved with molten metal. That is, the alloy is able to be received into the flow path in its molten state, from the pressurised source, and is able to remain in that state until it solidifies in the die cavity. This is unlike our earlier inventions based on use of a CEP, in which alloy in the molten state changes to a semi-solid state in which it is able to exhibit thixotropic properties. In this regard, the invention may be similar to conventional high pressure die casting practice. However, the invention differs further and significantly from that conventional practice.

With our earlier inventions based on use of a CEP, the resultant semi-solid alloy typically has a solids content such that it is able to exhibit thixotropic properties. For this, the alloy has in excess of about 25 wt% solids, usually at least about 30 wt% solids, such as up to about 60 to 65 wt%. While the present invention enables die cavity fill with molten metal, there are circumstances in which alloy received into the die cavity can have a low solids content. However,

the low solids content obtainable with the present invention is insufficient to enable the alloy to exhibit thixotropic properties.

With cold chamber pressure die casting machines, primary dendritic particles can form in the shot sleeve. These can range in size up to about 60 μm or larger and can be detrimental in a casting. Where the present invention is used in a cold chamber machine, it remains possible for such particles to form in the shot sleeve. Where this occurs, the particles in a modified form comprise or contribute to a solids content in alloy flowing into the die cavity.

It also is found that, with use of the present invention, a low level of solids can be formed as a consequence of flow of the alloy along the flow path. The weight percentage of these solids is insufficient to confer on the alloy the properties of alloy in a fully thixotropic condition. The solids content is at a level below about 25 wt%, such as below about 20 or 22 wt% and, more usually, less than about 17 wt%. This applies even if solids formed as a consequence of alloy flow along the flow path combine with solids resulting from primary dendritic particles formed in the shot sleeve, in the event of use of a cold chamber machine.

To the extent that solids are present in alloy flowing into the die cavity with use of the present invention, the solids have a very small particle size. This is able to be established by the microstructure of a sufficiently rapidly solidified casting produced with use of the invention. Thus, the castings are, able to exhibit microstructures having rounded primary dendritic particles of not more than about 50 μm in size, indicative of solids produced in flow of alloy along the flow path comprising particles of about that size or less.

The solids having a small particle size are indicative of the alloy being subjected to very intense shear forces in flow along the flow path. These forces result from the significant reduction in flow velocity for the alloy, as it passes through the FEM, from the flow velocity in the runner. The intensity of the forces is evidently from flow modelling determinations. The intense shear forces also is indicated by principal characteristics of the microstructure able to be achieved in a casting produced with use of the present invention.

A first microstructure characteristic is the above-mentioned rounded primary dendrite particles, and the fine particle size and uniform distribution of those particles. A second microstructure characteristic, in the case of use of a

cold chamber machine, is the substantial absence of larger, branched dendritic particles able to be formed in the shot sleeve. It seems that the shear forces are sufficiently intense as to break up such particles. A further characteristic, with both hot and cold chamber machines, is the substantial absence of pressure casting defects resulting from gas porosity. Rather than exhibiting such defects in segregated regions due to entrained gas, the microstructure of a casting produced by the present invention has any gas, resulting for example, from air entrapment, present in an exceedingly fine, substantially uniformly distributed form. The fineness and uniformity of distribution of any gas is such that adverse consequences for physical properties are substantially avoided.

The form of an FEM, in causing a decrease in alloy flow velocity is such that it necessarily increases in cross-sectional area in the direction of alloy flow. Alloy flow is able to be at a substantially fixed mass flow rate. However, due to the increasing cross-sectional area of the FEM, the alloy undergoes a progressive, but substantial reduction in flow velocity from the level at the outlet end of the runner to the location at which the alloy enters the die cavity. In causing a reduction in flow velocity, an FEM achieves a result similar to that achieved in a CEP. Despite this similarity, the reduction is not such as to cause the alloy to change from its molten state to a semi-solid state to an extent resulting in thixotropic properties, even if the alloy flow velocity in the runner is similar to that required at the inlet end of a CEP for that change of state. That is, the reduction in flow velocity in an FEM is such as to preclude the change of state, at least to that extent.

Due to its FEM increasing in cross-sectional area in the flow direction, a flow device according to the present invention is different from a flow system used in conventional die casting practice. In conventional practice, a substantially constant flow velocity usually is maintained, except at the location at which the flow path communicates with the die cavity. In a flow system used in conventional practice a constriction provided at that location, referred to as a gate, causes the alloy to undergo a sharp increase in flow velocity such that the alloy flows into the die cavity as a thin, high velocity jet. In the flow path according to the present invention, a gate constriction need not be provided and the alloy may flow into the die cavity as a relatively wide stream. In the metal flow device of the invention, the flow path may have a cross-section at the

location at which the flow path communicates with the die cavity which is larger than the cross-sectional area of the runner. In the conventional practice, the area of the gate is smaller than the cross-sectional area of its runner. However, while the flow path according to the invention need not have a gate constriction, this is not essential and a constricting gate can be provided in at least some instances. In any event, whether or not a constricting gate is provided, the flow path of the invention differs from conventional practice. The first part of the flow path which includes a runner is significantly smaller in cross-sectional area than a conventional runner. Also, the second part of the flow path, between the outlet end of the runner to the outlet end of the FEM, increases in cross-sectional area in the flow direction to thereby cause a required reduction in alloy flow velocity through the FEM. In these respects, the flow path is somewhat similar to that of PCT/AU03/00195, although there are necessary and important differences.

As indicated later herein, a runner flow velocity which is high relative to that used in conventional pressure die casting is required in use of the present invention. For a pressure casting machine operable to supply alloy at a given mass flow rate, the runner required for the invention necessarily has a smaller cross-sectional area relative to a conventional runner in order to achieve the higher flow velocity at that mass flow rate. In this respect, the runner of the present invention can be substantially the same as that required by the teaching of PCT/AU03/00195. However, in the flow path of the present invention, the alloy flow from the outlet end of the runner passes directly into an FEM. In contrast, in the arrangement of PCT/AU03/00195, the alloy flow from the outlet end of the runner passes directly into a CEP and, from the outlet of the CEP, directly or indirectly into an FEM. Moreover, the present invention limits the extent to which alloy is able to change its state to a semi-solid form, to obviate development of thixotropic properties. In contrast, the FEM in the arrangement of PCT/AU03/00195 is to facilitate maintenance of semi-solid alloy generated in the CEP and having thixotropic properties.

The outlet end of the FEM may be at the location at which the flow path communicates with the die cavity. While this is preferred, the outlet end of the FEM may be spaced from the location by a secondary runner which does not provide a significant restriction to alloy flow. Thus, the cross-sectional area of

the secondary runner may be substantially the same as the area of the outlet of the FEM. As will be appreciated, a secondary runner in the system of the invention will have a larger cross-sectional area than the runner of the first part of the flow path, and this is the converse of the relationship between a secondary and primary runner of conventional pressure casting practice.

The FEM in the device of the invention can take a variety of forms. In a first form, the FEM defines or comprises a channel which has a width which is substantially in excess of its depth and a transverse cross-sectional area greater than the area of the outlet of a runner from which it is able to receive molten alloy. In that first form the width of the channel, which may exceed its depth by at least an order of magnitude, preferably is disposed in a plane extending transversely with respect to the runner. The channel is such that it enables alloy flowing into it from the runner to spread in a radial fashion and thereby undergo a reduction in flow velocity. The cross-sectional area of the channel may increase in the direction of alloy flow to thereby cause a further decrease in alloy flow velocity.

In that first form, the channel may be substantially flat or, if appropriate for the die cavity for a given casting, it may be curved across its width. However, it alternatively can have a saw-toothed or corrugated configuration, to define peaks and troughs across its width, somewhat similar to some forms of chill vent. The channel may increase in cross-sectional area due to one of the width and depth of the channel may be constant along its length, with the other progressively increasing, preferably uniformly. However, if required, each of the width and depth may increase in the direction of alloy flow. With a saw-tooth or corrugated form, it generally is more convenient for only the width to increase, although this form has the benefit of maximising flow length for a given spacing between the runner outlet end and the location at which the flow path communicates with the die cavity.

With the first form, in which the FEM defines a channel having a width substantially in excess of its depth, the arrangement generally is such that the alloy flow path communicates with the die cavity through an opening having a width substantially in excess of its depth. This is well suited to die cavity fill by indirect or edge feed, particularly when the die cavity is for producing a thin casting.

In a second form, the FEM of a device according to the invention defines or comprises a channel having a width and depth which have dimensions of the same order, and a transverse cross-section which progressively increases in the direction of alloy flow. This form, in having a progressively increasing cross-section, also provides a required low flow velocity at the location at which the flow path communicates with the die cavity.

Subject to the form of the die cavity at the location at which the flow path communicates with it, the channel of the second form of the FEM may be open at its end remote from the runner from which it is able to receive molten alloy, with the open end defining that location. However, it is preferred that the location is defined by an elongate opening extending along a side of the channel. In that preferred arrangement, the channel may extend substantially linearly from the runner, along a side edge of the die cavity, with the elongate opening being along the side of the channel adjacent to the edge of the die cavity. However, it is preferred that the channel is curved, to facilitate it being of a suitable length, so as to provide an end portion of the channel remote from the runner which extends along a side edge of the die cavity. Particularly with such curved form of channel, the flow path may be bifurcated, beyond the runner in the direction of alloy flow, to provide at least two channels each having such an end portion with such elongate opening. In the bifurcated arrangement, the opening of each channel may provide communication with the die cavity at a common edge, or a respective edge, of the die cavity. Where two curved channels communicate with the die cavity at a common edge, the end of each channel remote from the runner may terminate a short distance from each other, such that their side openings are longitudinally spaced along the common edge of the die cavity. However, in an alternative arrangement, the two channels may merge at those ends to thereby form respective arms of closed loop, in which case the openings again may be so spaced, or they may form a single elongate opening common to each arm.

The progressive decrease in alloy flow velocity in the FEM of the metal flow system of the invention, and the progressive increase in cross-sectional area of that second part which causes that decrease, may be continuous. Also, the progressive decrease in velocity and increase in area may be substantially uniform, or it may be step-wise, along at least a section of the second part. The

first and second forms for the FEM described above are well suited to providing a continuous decrease in velocity, produced by a continuous increase in cross-sectional area, such as along at least a major part of the length of the second part.

In a third form, providing a step-wise decrease in flow velocity, the FEM includes a chamber into which alloy received from the runner flows, with the chamber achieving a step-wise reduction in the alloy flow velocity. In the third form, the FEM includes channel means which provides communication between the chamber and the die cavity and which has a form at least substantially maintaining the flow velocity level attained in the chamber. That communicating channel means may be of a form similar to that of the first form of FEM described, while it may have a substantially uniform or slightly increasing cross-section. Alternatively, the channel means may comprise at least one channel, but preferably at least two channels, similar to the second form of the FEM described above except that, if required, such channel or each such channel may have a substantially uniform cross-section.

The chamber of the third form can have a variety of suitable shapes. In one convenient arrangement, it may have the form of an annular disc. That arrangement is suitable for use where the communicating means is at least one channel. Where, in that arrangement, the communicating means comprises at least two channels, the channels may communicate with a common die cavity, or with a respective die cavity.

The at least one channel of the communicating means of the third form of FEM may open to its die cavity at an end opening of the channel, or at an elongate side opening as described with reference to the second form.

In each form of the invention, the FEM most preferably is disposed parallel to the parting plane of a mould defining the die cavity. The first part of the flow path may be similarly located, such that its runner also is parallel to that plane, with alloy received from a sprue or runner portion extending through one mould part to that plane. Alternatively, the first part of the flow path may extend through such mould part, with the outlet of the runner at or closely adjacent to the parting plane.

Flow velocities for use of a CEP in achieving a change in alloy from its molten state to a semi-solid state having thixotropic properties are detailed in

the above-mentioned patent applications. However, for a magnesium alloy, the flow velocity at the inlet end of the CEP generally is in excess of about 60 m/s, preferably at about 140 to 165 m/s. For an aluminium alloy, the inlet end flow velocity generally is in excess of 40 m/s, such as about 80 to 120 m/s. For other alloys, such as zinc and copper alloys, capable of being converted to a semi-solid state having thixotropic properties, the CEP inlet end flow velocity generally is similar to that for aluminium alloys, but can vary with the unique properties of individual alloys. The reduction in flow velocity to be achieved in the CEP generally is such as to achieve a flow velocity at the CEP outlet end which is from about 50 to 80%, such as from 65 to 75% of the flow velocity at the inlet end.

With use of a FEM in accordance with the present invention, a CEP is not used. Also, the alloy may remain molten in its flow to the die cavity but, even where some solids are formed, the alloy does not undergo a change of state to an extent resulting in thixotropic properties. Despite this, runner flow velocities, at least at the runner outlet end, can be similar to those required with use of a CEP. Thus, for magnesium, a flow velocity at the outlet end of the runner or the inlet end of the FEM can be in excess of about 60 m/s, and preferably is from about 130 m/s to 160 m/s, but can range up to about 180 m/s. For an aluminium alloy and other alloys, such as zinc and copper alloys, a flow velocity at the outlet end of the runner or inlet end of the FEM can be as detailed above for use of a CEP.

The reduction in flow velocity to be achieved in an FEM usually is very substantial. Indeed, the reduction can exceed that obtained in use of a CEP. Thus, whereas the reduction in flow velocity in a CEP is such that the flow velocity is from 50 to 80%, such as from 65 to 75%, of the flow velocity at the inlet end of the CEP, an FEM can achieve a greater reduction in flow velocity. Practical considerations favour an FEM having an effective flow length which is as short as possible. The length of an FEM varies with its average cross-sectional area, but may be from about 15 to 35 mm. Also, an FEM preferably has an overall length which is less than its effective flow length, due to it having an undulating, corrugated or saw-toothed configuration which increases back-pressure in the flow system.

As with a CEP, the length of an FEM varies with the cross-sectional area at the outlet end of the runner from which it receives a flow of alloy. As a CEP is to result in a change in the state of the alloy, from a molten state to a semi-solid state exhibiting thixotropic properties, it is to be expected that an FEM would have a shorter length than a CEP, for a given runner outlet end cross-sectional area. A longer length, providing a more gradual increase in cross-sectional area for a FEM from the runner inlet, would seem to be necessary for providing the conditions appropriate for avoiding a change of state at all, or at least to the extent required for a CEP. However, we have found that this is not the case. Rather, we have found that, for a given cross-sectional area at the outlet end of the runner, an FEM needs to have a shorter length than would be required for a CEP provided for such runner.

The preceding description of the invention makes reference to a die cavity or the die cavity. However, it is to be understood that the invention is applicable to multi-cavity moulds. In such case, the FEM defined by the system of the invention may divide or extend to provide separate flow to a common die cavity or to each of at least two die cavities. Indeed, as illustrated herein by reference to the drawings, providing such separate flow from a common FEM generally facilitates attainment of the required reduction in alloy flow velocity.

In order that the invention may more readily be understood, description now is directed to the accompanying drawings, in which:

Figure 1 is a schematic representation of a two cavity mould arrangement, taken on the parting plane between fixed and movable mould parts, illustrating a first embodiment of the invention;

Figure 2 is a sectional view taken on line II of Figure 1 and shown on an enlarged scale;

Figure 3 is a schematic representation, similar to Figure 1, but illustrating a second embodiment of the invention having a single die cavity;

Figure 4 is a side elevation of the arrangement of Figure 3;

Figure 5 is similar to Figure 4, but shows a first variant of the second embodiment;

Figure 6 is similar to Figure 4 but shows a second variant of the second embodiment;

Figure 7 is similar to Figure 3, but illustrates a third embodiment of the invention;

Figure 8 is a side elevation of the arrangement of Figure 7;

Figure 9 is a schematic representation, similar to Figure 1, but illustrating a fourth embodiment of the invention;

Figure 10 is a part sectional view taken on line X-X of Figure 9;

Figure 11 is similar to Figure 3, but illustrates a fifth embodiment of the invention;

Figure 12 is a part sectional view taken on line XII-XII of Figure 1;

Figure 13 is similar to Figure 11, but shows a first variant of the fifth embodiment of the invention;

Figure 14 is similar to Figure 11, but shows a second variant of the fifth embodiment;

Figure 15 is a part sectional view taken on line XV-XV of Figure 14;

Figure 16 is similar to Figure 3, but illustrates a sixth embodiment of the invention;

Figure 17 is a side elevation of the arrangement of Figure 16;

Figure 18 is similar to Figure 17, but illustrates a variant on the sixth embodiment;

Figure 19 is a plan view of a casting produced using a seventh embodiment of the present invention;

Figure 20 is a schematic representation of part of the seventh embodiment in plan view; and

Figure 21 is a side elevation of the arrangement shown in Figure 20.

With reference to Figures 1 and 2, there is represented therein two die cavities 10 and 11, defined by fixed mould half 12 and movable mould half 13 and each for use in producing a respective casting in a high pressure casting machine (not shown). Each of die cavities 10 and 11 is arranged to receive alloy from a pressurised supply of molten alloy of the machine, with alloy passing to each cavity by a common alloy feed device 14 according to a first embodiment of the present invention. The embodiment is one in accordance with the first form of the invention as described above.

The alloy feed device 14 defines a flow path for molten alloy which has a first part defined by nozzle 16, shown in more detail in Figure 2, and a second

part 18, referred to as an FEM as identified earlier herein, which extends between each cavity and across the outlet end of nozzle 16.

In overall form and detail, nozzle 16 includes an elongate annular housing 20 by which the first part of the metal flow path defines a bore comprising a runner 22. Housing 20 has its outlet end neatly received in an insert 26 of fixed mould half 12, while its inlet end abuts against a fitting 28 of platen 29. Around housing 20 there is an electric resistance coil 30 and, outside coil 30, a layer of insulation 32. Also, an insulating gap 34 is provided between insulation 32 and insert 26, except for a short distance at the outlet end of housing 20 where the latter is in metal to metal contact with insert 26. Additionally, gap 34 extends between insulation 32 and fitting 28. Coil 30 and insulation 32 provide for control of heat energy level of housing 20 and the temperature of alloy flowing through runner 22.

In the arrangement of nozzle 16, runner 22 is of constant cross-section throughout its length, except for a short distance at its outlet end at which it tapers down to the cross-section of the outlet end 22a of runner 22. From the outlet end 22a of runner 22, the bore of housing 20 flares over a very short end portion 35. This may provide a transition to the FEM 18 of the metal flow path and, like FEM 18, serves to reduce the flow velocity of the alloy relative to its level at end 22a of runner 22. Alternatively, that flared end portion 35 may co-operate with a spreader cone, such as described with reference to Figures 3 and 4, in which case the flared end portion 35 may provide a more significant reduction in alloy flow velocity.

The FEM 18 of the alloy flow path is defined by a shallow, rectangular channel 36 into the centre of which the bore of housing 20 opens. Channel 36 is defined by mould halves 12 and 13, and has its width and length dimensions parallel to the parting plane P-P between mould halves 12 and 13. Thus, channel 36 is perpendicular to nozzle 16.

Channel 36 provides alloy flow to each of the die cavities 10 and 11 in which the alloy flow velocity decreases below the level prevailing at outlet end 22a of runner 22. This is achieved by the alloy spreading radially outwardly in channel 36, from end 22a, as represented by the broken circles shown in Figure 1. Thus, the molten alloy is able to progress on an expanding front in channel 36 which is tangential to radial directions from end 22a. The expanding flow of

alloy is constrained on reaching the opposite sides of channel 36, but is divided to continue to flow at a reduced flow velocity to each of open ends 36a and 36b of channel 36 by which channel 36 communicates with die cavities 10 and 11, respectively. Over the portion of channel 36 leading to die cavity 10, the opposite sides of channel 36 are substantially parallel, such that required, reduced flow velocity for cavity 10 may be attained a short distance before open end 36a. However, for the portion of channel 36 leading to cavity 11, the opposite sides diverge in the flow direction, such that the flow velocity is able to continue to decrease to obtain a different required, reduced flow velocity at open end 36b for cavity 11. Alloy flow continues to achieve filling of each die cavity 10,11. Alloy flow throughout each of cavities 10,11 is able to be at a sufficiently low flow velocity, below the flow velocity at end 22a of runner 22, that back pressure against alloy flow is able to be maintained at a suitable level.

The arrangement of mould halves 12,13 is such that heat energy extraction from alloy in each die cavity 10,11, on completion of cavity fill, provides rapid solidification of alloy in each cavity 10,11 and back along channel 36 to the outlet end 22a of runner 22. The thin cross-section of channel 36 facilitates this. Also, heat energy extraction, principally by die half 12 and its insert 26, enables that cooling to progress back into the end 22a, despite heating by coil 30, due to the metal to metal contact between housing 20 and insert 26, around end 22a.

Figures 3 and 4 show a second embodiment of an arrangement for producing a casting, in this case using a single cavity mould of a high pressure casting machine. The second embodiment also is in accordance with the first form of the invention as described above, but utilises a saw-toothed like channel form, rather than a flat channel as in Figures 1 and 2. Parts corresponding to those of Figures 1 and 2 have the same reference numeral, plus 100. However, the mould halves are not shown, while only part of housing 120 of a nozzle 116 is illustrated.

In Figures 3 and 4, the end of channel 136 of FEM 118 has a round-ended flat portion 40 with which the runner 122 communicates. Also, as indicated above, channel 136 has a portion 42, between portion 40 and die cavity 110 which has a saw-toothed form defining peaks 42a and troughs 42b

which extend transversely with respect to the direction of alloy flow through portion 42.

While the movable die half is not shown, there is illustrated a spreader cone 46 of that half. With the mould die halves clamped together, cone 46 is received within flared end portion 135 of the bore of nozzle housing 120, beyond the outlet end 122a of runner 122. Thus, alloy flowing from runner 122 spreads frusto-conically prior to entering channel 136. Depending on the cone angles of portion 135 and core 46, the flow velocity of alloy entering channel 136 may be the same as, or slightly different from that attained at outlet end 122a of runner 122, although it usually will be substantially unchanged.

Within channel 136, the molten alloy received from runner 122 first spreads radially and thereby decreases in flow velocity. On flowing through portion 42 of channel 136, the flow velocity is further decreased through to open end 136a, due to the opposite sides of channel 136 diverging to end 136a. Thus, alloy flowing into and filling die cavity 110 is able to be maintained with a suitable back pressure. The saw-toothed like configuration (with one or more than one tooth) of portion 42 of channel 136 increases the back-pressure to a required level. Apart from the differences detailed, overall performance with the arrangement of Figures 3 and 4 is substantially as described with reference to Figures 1 and 2.

Figure 5 shows a first variant of the embodiment of Figures 3 and 4. The variant of Figure 5 is the same in overall form to that of Figures 3 and 4, except that the outlet end 122a of runner 122 communicates directly with channel 136. That is, there is no flared portion for the bore of housing 120, and a spreader cone therefore is not required.

The partial view of Figure 6 (in which the die cavity is not shown) illustrates a second variant of the embodiment of Figures 3 and 4. The variant of Figure 6 is the same in overall form as Figures 3 and 4, except that portion 42 of the channel 136 of the FEM 118 is of an undulating or corrugated configuration, rather than saw-toothed. However, that configuration of Figure 6 again provides suitable back-pressure.

The third embodiment of Figures 7 and 8 also is in accordance with the first form of the invention as described above. In the arrangement of Figures 7

and 8, parts corresponding to those of Figures 1 and 2 have the same reference numeral, plus 200.

As with the embodiment of Figures 3 and 4, the third embodiment of Figures 7 and 8 is for producing a casting using a single cavity mould. However, in this case, channel 236 of the FEM 118 does not include a portion of saw-toothed configuration. Rather, channel 236 has flat top and bottom main surfaces. Also, while those surfaces converge slightly in the direction of alloy flow therethrough, to outlet end 236a and cavity 210, the opposite sides of channel 236 diverge in that direction. The arrangement is such that, in the flow direction, channel 236 increases in transverse cross-sectional area towards the elongate, thin open end 236a, such that alloy flow velocity progressively decreases to a suitable level at end 236a which is significantly below that at outlet end 222a of runner 222.

In the embodiment of Figures 7 and 8, runner 222 extends parallel to the parting plane P-P between mould halves 212,213, and provides communication with the end of channel 236 remote from die cavity 210. The runner 222 is defined by the halves 212,213, rather than by a nozzle, while runner 222 is aligned with a centre-line of channel 236 of the FEM 218 and cavity 210. The supply of alloy to the inlet end of runner 222 may be via a main runner or the bore of a nozzle, with such main runner or nozzle bore extending through fixed mould half 212, such as perpendicularly with respect to plane P-P.

Within channel 236, there is an arcuate wall 50 which extends between the top and bottom main surfaces of channel 236. Wall 50 defines a recess 52 which opens towards the outlet end 222a of runner 222, such that any solid slug or the like from a previous casting cycle, carried into chamber 236 with the alloy, is able to be captured and retained.

Operation with the embodiment of Figures 7 and 9 generally will be appreciated from description in respect of Figures 1 and 2, and of Figures 3 and 4.

The fourth embodiment of Figures 9 and 10 is similar in many respects to the first embodiment of Figures 1 and 2. Figures 9 and 10 also are in accordance with the first form of the invention as described above, and the parts corresponding to those of Figures 1 and 2 have the same reference numeral, plus 300.

In the embodiment of Figures 9 and 10, the arrangement again provides for the production of castings, using a high pressure casting machine. The machine has a mould which defines two die cavities 310,311 between its mould halves 312,313. The die halves also define an elongate channel 336 which extends between cavities 310,311, parallel to the parting plane P-P. The channel 336 forms the FEM 318 of a molten alloy flow path of which the first part is provided by a runner 322. The runner 322 is defined by the housing 320 of a nozzle mounted in the fixed mould half 312 at right angles to plane P-P. The runner 322 communicates with channel 336 mid-way between cavities 310,311, such that the alloy is divided to flow in opposite directions to each cavity 310,311.

From the outlet end 322a of runner 322, the alloy spreads in end portion 335 of the bore of housing 320 and then enters a central region 54 of channel 336. At the region 54, the depth of channel 336 is increased such that region 54 provides a circular recess which can assist in stabilising alloy flow. From region 54, the alloy is divided so as to flow in opposite directions to each open end 336a and 336b of channel 336, and then into the respective die cavity 310,311.

Alloy received into runner 322, from a pressurised source of the machine, is caused to undergo a decrease in flow velocity in the FEM 318. The alloy flow path is such that the flow velocity is decreased in end portion 335 from the value at the outlet end 322a of runner 322, and then further decreased through to respective open ends 336a,336b of channel 336. This further decrease results from the alloy spreading radially from the outlet end of housing 320, in region 54, to the extent permitted by the opposite sides of channel 336. The alloy then flows along channel 336, to each of the opposite ends 336a and 336b, in which the flow velocity continues to decrease due to the opposite sides diverging slightly from region 54 to the opposite ends 336a, 336b. Finally, as channel 336 is inclined at an angle to the end of each die cavity 310,311 at which open ends 336a and 336b, respectively, provide communication, the ends 336a and 336b have a greater area than transverse cross-sections normal to the longitudinal extent of channel 336, thereby enabling a further reduction in alloy flow velocity at ends 336a and 336b.

The arrangement is such that alloy passing through open ends 336a and 336b has a flow velocity which is substantially lower than the flow velocity at the outlet end 322a of runner 322. The substantially lower flow velocity is such as to facilitate maintenance of a sufficient back pressure on the alloy during filling of die cavities 310,311. The arrangement also facilitates rapid solidification of alloy in cavities 310,311, on completion of die fill, such that solidification is able to proceed rapidly back from cavities 310,311, along channel 336 and to end 322a of runner 322.

In one example in accordance with Figure 9, the combined area of open ends 336a,336b of channel 336 can be about 45% greater than the area at outlet end 322a of runner 322, resulting in a corresponding reduction in flow velocity at ends 336a,336b. In this regard, it will be appreciated that while each open end 336a,336b has an area less than that at runner end 322a, each open end 336a,336b accommodated approximately half of the total alloy flow (as in the case of ends 36a,36b of the arrangement of Figures 1 and 2).

In the example, the open ends 336a,336b can have a width of 30mm and a depth of 0.9mm. The arrangement is suitable for a die cavity 310 having a 2mm depth dimension normal to the plane P-P, with the cavity 311 having a corresponding dimension of 1mm. In each die cavity, the alloy is able to flow on a front, to achieve die cavity fill, which spreads as it moved away from the respective open end 336a,336b. Thus, alloy flow velocity further decreased in each cavity 310,311, is able to maintain a sufficient back pressure.

In the arrangement of Figures 9 and 10, the inclination of open ends 336a,336b is such as to direct alloy across a corner of the respective cavity 310,311, and this is found to be beneficial. This inclination has been found to increase back-pressure against alloy flow. Also, adjacent to end 336b, channel 336 was provided with a short length 336c which was inclined with respect to plane P-P, with this also assisting maintenance of a suitable back-pressure.

Figures 11 and 12 illustrate a fifth embodiment of the invention which is in accordance with the second form of the invention described above. In Figures 11 and 12, the alloy flow device shown has an alloy flow path which extends parallel to the parting plane P-P between fix mould half 60 and movable mould half 61, to die cavity 62. The flow path includes a runner 63 which defines a first part of the flow path. The second part of the flow path comprises

an FEM in the form of a channel 66 which has oppositely facing C-shaped arms 67,68. Only part of arm 67 is shown, although it is of the same form as arm 68, but oppositely facing.

Each arm 67,68 of FEM channel 66 has a respective first portion 67a,68a which extends laterally outwardly from an enlargement 69 at the outlet end 63a of runner 63. From the outer end of portion 68a, arm 68 has a second portion 68b which extends in the same direction as, but away from, runner 63. Beyond portion 68b, arm 68 has a third portion 68c which extends laterally inwardly towards a continuation of the line of runner 63. While not shown, arm 67 also has respective second and third portions, beyond portion 67a, which correspond to portions 68b and 68c of arm 68. Each arm 67,68 provides communication with the die cavity 62, within a U-shaped recess 72 at an end of cavity 62.

Runner 63 and FEM channel 66 are of bi-laterally symmetrical trapezoidal form in transverse cross-section, as shown for portion 67a of arm 67 in Figure 12. Runner 63 is of uniform cross-sectional area over the major part of its length but, adjacent to its outlet end, it tapers down to the area at the outlet end 63a of runner 63. From the enlargement 69 of the flow path, each arm 67,68 of channel 66 increases in cross-sectional area to a maximum adjacent to its remote end.

An example was based on Figures 11 and 12, and suitable for production of magnesium alloy castings on a hot chamber pressure die casting machine with a single die cavity mould, could have an arrangement such that molten magnesium alloy from the machine source was supplied under pressure to the inlet end of runner 63 in which the flow velocity was 50 m/sec. At the taper to the outlet end 63a of the runner 63, the molten alloy flow velocity was increased to attain 112.5 m/s. From enlargement 69, the alloy divided equally for flow along each arm. Relative to the locations A to E shown for arm 68, the alloy flow velocity could decrease progressively to 90 m/sec at A, 80 m/sec at B, 70 m/sec at C, 60 m/sec at D, and 50 m/sec at E.

Each arm was provided with an elongate opening by which it was in communication with the die cavity 62. Relative to the locations C,D,E and the end of arm 68, the opening for arm 68 (and similarly for arm 67) could have an average width of 0.5mm from C to D, of 0.6mm from D to E and of 0.8mm from

E to the end. The overall length of each slot therefore would be 35.85mm, with the overall alloy flow velocity therethrough decreasing from 70 m/sec at C to less than 50 m/s at the end of each arm beyond E.

Figure 13 shows a variant on the arrangement of Figures 11 and 12, and corresponding parts have the same reference numerals, plus 100. Figure 13 shows a main runner 70 by which alloy is supplied to runner 163. In this instance, arms 167,168 of FEM channel 166 each communicate with the die cavity along a straight end of the cavity. The arrangement, for use with a magnesium alloy, could provide for a molten alloy flow velocity of 150 m/sec at outlet end 163a of runner 163. In each arm of channel 166, the alloy flow velocity could decrease to 125 m/sec at A, 110 m/sec at B, 95 m/sec at C and 80 m/sec at the end of each arm 167,168. The opening from each arm to the die cavity is from just before each location D to the end of each arm. Operation with this arrangement is as described for Figures 11 and 12.

Figures 14 and 15 show more precise detail for the variant of Figure 13, for the runner 163 and channel FEM 166. For this, suitable cross-sectional areas for a magnesium-alloy and flow velocities as detailed in relation to Figure 13 are as follows:

Location	Area (mm^2)
163a	8.5
A	6.0
B	6.8
C	8.0
D	9.6.

As will be appreciated, the areas shown for locations A to D are for one arm of FEM channel 166. However, relating these to the areas for outlet end 163a of runner 163 needs to take into account the fact that each arm provides for the flow of only half of the alloy flowing through the runner.

Figure 16 shows part of the flow device for a further embodiment of the present invention, viewed perpendicularly of a parting plane. Figures 17 and 18 show alternatives for the arrangement of Figure 16.

In Figures 16 to 18, the runner by which molten alloy flows is shown only at a terminal portion 80 defining outlet end 80a. However, runner 80 forms the first part of the flow path of the flow system, while channel 82, chamber 84 and

channels 86 form the second part or FEM of the flow system. Molten alloy flows from runner 80 to channel 82, into chamber 84, and the alloy then flows through each channel 86 to a single or respective die cavity (not shown). Channel 82 has a larger cross-sectional area than the outlet end of runner 80, and the cross-sectional may be constant or it may increase to chamber 84. In either case, it provides a lower alloy flow velocity than that attained at the outlet end of runner 80. In chamber 84, the alloy flow is able to spread, resulting in a further reduction in flow velocity. From chamber 84, the alloy flow divides to extend along each channel 86 and, like channel 82, each of channels 86 provides for a further reduction of alloy flow velocity therein or therealong. Given the division of alloy flow, channels 86 may have a lesser cross-sectional area than channel 82, while still achieving a reduction in flow velocity.

Chamber 84 may be thinner than channel 82 and channels 86 as shown in Figure 17, or it may be thicker as shown in Figure 18. It alternatively may be of similar thickness to the channels.

Operation with the arrangement of Figures 16 to 18 generally will be understood from description with reference to preceding embodiments.

Figure 19 illustrates a casting 90 able to be produced using a further embodiment of the present invention. The casting comprises a pair of laterally adjacent tensile bars 91 joined in series at adjacent ends by a tie 92 of metal which solidified in a channel providing for metal flow between respective die cavities in which the bars 91 were cast. The casting 90 is illustrated in an as cast condition and it accordingly includes metal 93 solidified along part of the metal flow path by which alloy was supplied to the die cavities. The metal 93 includes metal section 94 solidified in the FEM, and metal section 95 solidified in the runner, of the metal flow path.

To obtain the tensile bars 91, the casting 90 would be cut along the junction between each end of tie 92 and the respective side of each bar 91 while metal 93 would be severed from the side of the tensile bar 91 to which it is attached. The shape of the severed metal 93 is shown in more detail in Figures 20 and 21. The metal 93 of course has the same form as a corresponding section 96 of a metal flow device according to the present invention and further description of metal 93 in Figures 20 and 21 is with reference to metal 93 as if representing that corresponding section 96. Metal sections 94 and 95 thus are

taken as respectively representing the FEM 97 and the runner 98 of the corresponding metal flow system. The shading depicts respective mould halves 101 and 102 which are separable on parting line P-P and which define the die cavities and metal flow system.

As can be seen from Figures 20 and 21, the FEM 97 has an overall rectangular form, with the runner 98 longitudinally in-line. The outlet end 98a of the runner 98 communicates with the FEM 97 at the middle of one end of the FEM. Thus, the molten alloy flows along runner 98 and, from runner 98, the alloy flows through the FEM 97 towards its end remote from the runner outlet 98a. However, towards that remote end, the FEM 97 opens laterally to a short secondary runner 100 through which alloy is able to pass to the first of in-series die cavities in which tensile bars 91 are cast.

Along a first part of its length from runner outlet 98a, the FEM 97 is of a form which generates resistance to alloy flow therethrough. This is achieved by alternate ribs 101a and 102a, defined by the respective mould parts, which extend laterally with respect to alloy flow through the FEM 97, and which protrude into the general rectangular form of the FEM. The width of the FEM 97 and the minimum distance A between successive ribs is calculated so that a required flow velocity for a given alloy is achieved. Thus, for example, a molten magnesium alloy may be reduced in flow velocity from 150 m/s at inlet 98a of runner 98 in its flow through FEM 97.

In the embodiments illustrated in the drawings, the molten alloy flow velocity in the runner preferably is very substantial, as detailed earlier herein. Thus, for a magnesium alloy, the flow velocity in the runner and at the inlet to the FEM can be in excess of 60 m/s such as up to about 180 m/s, but preferably is from about 130 m/s to 160 m/s. For other alloys, such as aluminium, zinc and copper alloys, the flow velocity can be in excess of 40 m/s such as up to about 160 m/s, but preferably is from about 80 to 120 m/s. The consequence of this is that, for a pressurised source of molten alloy able to generate a given alloy mass flow rate, the runners used in the invention have a correspondingly smaller cross-section relative to runners necessary for accommodating the very much smaller runner flow velocities used in conventional pressure die casting. This facilitates retraction of molten alloy back along the runner, from a solid/liquid interface on completion of a casting cycle, where that interface is to

be closely adjacent to the outlet end of the runner. Also control of the temperature of molten alloy in the runner is more readily facilitated, due to the reduced mass of molten alloy in the runner.

The more desirable alloy runner flow velocity, within the above indicated ranges, varies with the form of FEM used and with the form and size of the casting being produced. The form of the FEM, in particular its effective flow path length, can vary with the reduction in alloy flow velocity to be achieved in the FEM. The reduction in flow velocity to be achieved in an FEM usually is in excess of 20%, but preferably is in excess of 30%, and can be in excess of 50% of the runner flow velocity. It usually is necessary to achieve higher levels of flow velocity reduction with use of higher runner flow velocities. In any event, the reduction in flow velocity is to be sufficiently gradual as to avoid substantially a change in the alloy from a molten state to a semi-solid state in which it exhibits thixotropic properties, at least during its flow to the inlet to the die cavity.

As detailed herein, the FEM achieves a reduction in flow velocity by increasing the cross-sectional area of the flow path, from the area at the outlet end of the runner. The reduction in flow velocity can be to a level used in conventional die casting. As a consequence, the increase in cross-sectional area along the FEM can be to an area at its outlet end which is similar to the cross-sectional area of a conventional runner. Despite this, the volume of the FEM is substantially less than the volume of a corresponding length of a conventional runner. This, combined with the substantially smaller runner cross-sections required by the invention, results in the volume of metal which solidifies in the flow system on completion of a casting cycle, and which needs to be removed from a casting and recycled, being substantially less than the sprue/runner metal recycled in conventional practice. Thus, less shot weight is required for each casting cycle in producing a given casting, and this leads to other benefits in lower recycling cost, faster cycle time, reduced projected area, and in at least some cases use of colder dies. However, importantly, in addition to these benefits, the invention enables production of successful castings, even if these do not always have the low inherent level of porosity that results from semi-solid fill achieved by use of a CEP.

Each metal flow device of the embodiments of Figures 1 to 21 will vary with the machine with which it is to be used. Thus, the device needs to be operable in the required manner at an alloy mass flow rate at which the machine is operable. Thus, the runner of the first part of the flow path of the device needs to have a cross-sectional area which generates a required alloy flow velocity therein at that mass flow rate. That cross-sectional area need not prevail throughout the length of the runner, and may for example, be provided only at an outlet end portion of the runner. Thus, at that end portion, the runner may step down from a larger cross-sectional area so that the required flow velocity is attained in the outlet end portion. Additionally, the FEM is to have a length, and is to increase in cross-sectional area along that length in the flow direction, such that shear forces generated in the alloy are not such as to change the state of the alloy to a semi-solid state having thixotropic properties. If the shear generates any solids in the alloy, this should be to an extent of less than 25%, preferably less than about 20 to 22%, such as less than about 17 wt%. However, it is not necessary that any solids be generated at all, since even in this case, a superior microstructure as detailed above is found to be achieved. That is, it appears that the intense shear forces condition fully molten alloy so that such microstructure is achieved on solidification of cast alloy. The shear forces evidently assist in generating nuclei or nucleating melt surfaces.

A range of commercial castings were produced, in two dual series of trials, under conventional practice and operation in accordance with the present invention. In a first series, magnesium alloy castings were made on a (type and capacity) hot chamber machine. In a second series, aluminium alloy castings were made on a (type and capacity) cold chamber machine. For the magnesium castings, details common to conventional practice and to practice according to the invention are set out in Table 1, while features specific to each mode of practice are respectively set out in Tables 2 and 3. For the aluminium castings, the corresponding data is set out in Tables 4 to 6. In each of tables 2, 3, 5 and 6 the average piston velocity values, and the average runner velocity values, are for 2nd stage, fast fill operating conditions.

Table 1

Magnesium Alloy Castings

Trial	Trial Product	Alloy	Mass (g)	No. of Cavities	Piston Diameter (mm)
M1	Steering Wheel (1)	AM60B	615	1	63.5
M2	Steering Wheel (2)	AM60B	615	1	63.5
M3	Steering Wheel (3)	AM60B	675	1	63.5
M4	Transmission Case	AZ91D	3100	1	101.6

Table 2

Magnesium Alloy Castings – Conventional Practice

Trial	Av. Piston Velocity m/s	Runner Area (mm^2)		Average Runner Velocity (m/s)		Gate Area (mm^2)	Gate Velocity (m/s)
		Max	Min	Min	Max		
M1	1.6	552	230	9.18	22.03	166	30.52
M2	1.6	552	230	9.18	22.03	166	30.52
M3	3.9	506	276	24.41	44.75	172	71.81
M4	3.4	1800	750	15.31	36.75	690	39.95

Table 3

Magnesium Castings – Practice with Invention

Trial	Av. Piston Velocity m/s	Runner Area (mm^2)		Average Runner Velocity (m/s)		Gate Area (mm^2)	Gate Velocity (m/s)
		Max	Min	Min	Max		
M1	2.1	144	48.75	46.18	136.42	166	40.06
M2	1.8	144	48.75	39.59	116.93	166	34.34
M3	3.9	144	82.21	85.77	149.15	166	74.40
M4	3.4	250	181.50	110.26	151.87	690	39.95

Table 4

Aluminium Alloy Castings

Trial	Product	Alloy	Mass (g)	No. of Cavities	Piston Diameter (mm)
A1	Transmission Cover (1)	ADC12	875	2	95
A2	Transmission Cover (2)	ADC12	875	2	95
A3	Transmission Cover (3)	ADC12	875	2	95
A4	Extension Housing	ADC12	3400	1	80
A5	Hydraulic Plate	A380	540	4	88.9
A6	Hydraulic Body	A380	2500	2	98.5
A7	Water Pump	AS9U3	462	8	90
A8	Bracket	LM24	580	1	70
A9	Bracket	LM24	580	1	70
A10	Heat Sink	A380	3310	1	100

Table 5

Aluminium Alloy Castings – Conventional Practice

Trial	Av. Piston Velocity m/s	Runner Area (mm^2)		Average Runner Velocity (m/s)		Gate Area (mm^2)	Gate Velocity (m/s)
		Max	Min	Min	Max		
A1	1.5	990	405	10.74	13.13	126	42.19
A2	1.5	990	405	10.74	13.13	126	42.19
A3	1.5	990	405	10.74	13.13	126	42.19
A4	2.55	2150	300	5.96	42.73	227	56.47
A5	2.0	576	150	21.55	20.69	80	38.79
A6	3.8	2880	560	10.05	25.85	305	47.47
A7	5.0	3125	360	10.18	11.04	97	40.99
A8	2.3	600	270	14.75	32.78	220	40.23
A9	2.3	600	270	14.75	32.78	220	40.23
A10	3.2	1425	1400	17.64	17.95	602	41.75

Table 6

Aluminium Alloy Castings – Practice with Invention

Trial	Av. Piston Velocity m/s	Runner Area (mm^2)		Average Runner Velocity (m/s)		Gate Area (mm^2)	Gate Velocity (m/s)
		Max	Min	Min	Max		
A1	1.4	200	49.02	49.62	101.23	126	39.38
A2	1.7	240	60.82	50.21	99.06	126	47.82
A3	2.7	280	96.77	68.35	98.89	126	75.95
A4	2.55	144	128.0	89.01	100.14	227	56.47
A5	2.1	200	128.0	65.18	101.84	80	40.73
A6	3.8	388	294.0	74.63	98.49	305	47.47
A7	5.0	1875	41.85	16.96	95.00	97	40.99
A8	2.0	120	72.25	64.14	106.53	220	34.99
A9	2.2	120	72.25	70.56	117.18	166	51.00
A10	3.2	300	230	83.78	109.27	602	41.75

A respective magnesium alloy casting for each of the products detailed in Table 1 was produced under the conventional casting conditions detailed in Table 2, and under the conditions in accordance with the present invention detailed in Table 3. For each casting made under conditions detailed in Table 3, there was used a metal flow device corresponding to the embodiment illustrated in Figures 14 and 15. Each of the castings for which details are provided in Table 2 or Table 3 was found to be sound. However, those produced in accordance with the invention exhibited a superior microstructure. This superiority was in terms of greater uniformity of microstructure throughout the castings and the form of the constituents of the microstructure. The castings produced under conventional conditions exhibited larger individual grains of a normal, branched dendritic pattern and, in several instances, regions of porosity to levels of 1.5% or greater resulting from air entrapment. In contrast, the castings made in accordance with the present invention exhibited fine, spheroidal or rounded individual grains. Also, the latter castings were substantially free of regions of porosity and, to the extent that porosity could be determined, it appeared to be at a level less than 1.5% and substantially uniformly and very finely distributed.

The microstructures of castings M1, M2 and M3 produced in accordance with the present invention were indicative die cavity fill with alloy having a relatively small level of solids content of less than about 20%. This was not the case with the microstructure of casting M4, as it was indicative of die cavity fill with alloy having little if any solids content. However, in the case of casting M4, remelting of solids may have occurred in the die cavity due to the relatively large mass of the transmission case and resultant slower cooling.

A respective aluminium alloy casting for each of the products detailed in Table 4 was similarly produced under the conditions of Table 5 (conventional) and Table 6 (the invention). Each of the castings made in Trials A1 and A2 under the conditions of Table 6 used a metal flow device corresponding to the embodiment of Figures 20 and 21. Those of Trials A3 and A5 used a device corresponding to that of Figures 14 and 15. Those of Trials A4 and each of A6 to A10 used an experimental device described below. Again, each casting made according to the invention exhibited a superior microstructure compared with the microstructure of the corresponding casting made under conventional conditions. The differences in microstructures were essentially as detailed above in respect of the magnesium alloy castings.

The microstructures for the brackets of castings A8 and A9 appeared clearly to have resulted from die cavity fill with molten alloy having negligible if any solids content. The situation was less clear with the microstructures of castings A1 to A7, although it appeared that each of these resulted from die cavity fill with only a very minor solids content. None of the microstructures for castings A1 to A9 exhibited large isolated grains resulting from primary phase solidification in the shot sleeve. In each case, it appeared that if any such large grains were formed in the shot sleeve, they were broken down, increasing the number of finer grains, under the intense shear forces prevailing in the FEM.

The above-mentioned experimental metal flow device used for Trials A4 and each of A6 to A10 was formed in a respective face of each mould part which defines the parting plane between those parts. That is, both the runner and the FEM extended along the parting plane. Viewed perpendicularly to that plane, the FEM has side edges which diverged from each other in a direction away from the outlet end of the runner to an elongate gate which extended laterally with respect to the length of the runner. The runner thus ended at the

apex of a FEM which, in that view, was of a delta or triangular form. Viewed in side elevation, parallel to the parting plane, the FEM was curved or arched between the outlet end of the runner and the gate, due to the face of one mould part being convex and the face of the other mould part being concave. The arrangement was such that convex surface portion curved across the end of the runner so that alloy flowing from the outlet of the runner was deflected by that surface portion to cause the alloy to fill the triangular volume of the FEM in passing to the elongate gate.

Finally, it is to be understood that various alterations, modifications and/or additions may be introduced into the constructions and arrangements of parts previously described without departing from the spirit or ambit of the invention.